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SYNTHESIS OF MAJOR ECONOMIC STUDIES OF RESIDENTIAL PHOTOVOLTAICS

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Study Synopses

I. Summary

The purpose of this report is to provide summary documentation of major studies addressing the long-term economic potential of grid-connected residential photovoltaics in the U.S. Specific objectives of the report are:

- To summarize the key findings of each study.
- To identify the major differences among the studies.
- To identify key economic issues affecting grid-connected residential photovoltaics.

Six major studies of residential photovoltaic system economics were reviewed. The major conclusions reached in this review are listed below.

- General Observation: There is considerable variation among the report results, but the differences can largely be attributed to economic assumptions.

- Residential Photovoltaic Economics: Given financing and tax incentives, residential photovoltaic systems are attractive in many areas of the U.S. at prices of $0.70-$1.40/Wp for modules and $1.60-$3.20/Wp for installed systems (1980 dollars).

  - The studies differ in their estimates of balance of system costs, with estimates ranging from $0.75/Wp to over $2.00/Wp. If balance of system costs are at the upper end of this range, module costs must be near zero for systems to be cost-effective without special tax and financing incentives.

  - The cost-effectiveness of photovoltaic systems with storage depends upon the level of investment made to add storage capacity, the net expense saved by keeping the PV electricity on-site and the revenue that could be generated by selling electricity to the grid. Low battery costs, low utility buy-back rates and high electricity purchase rates improve the cost-effectiveness of storage systems. As battery costs and utility buy-back rates increase, storage becomes less cost-effective.

- Sensitivity Tests: Within a reasonable range, the cost-effectiveness of residential photovoltaic systems is significantly improved when all or some of the following conditions exist in the market: high electricity buy-back rates, real escalation rates of at least 2-3 percent applied to the electricity rates, high system electricity output and availability of tax incentives and favorable financing.

- Analytical Methods: When purchase criteria employed by the studies are comparably stringent (i.e., five-year payback) or relaxed (i.e., 10 percent discount, 20-year life, discounted cash flow analysis), similar cost-effective capital cost levels are derived.

II. Introduction

During the past several years, numerous economic analyses have addressed the future viability of grid-connected residential photovoltaics. These reports have varied widely in the assumptions used and the results reported. The Solar Energy Research Institute has completed a survey of studies dealing with all aspects of residential photovoltaic applications.[1] The survey has two stated purposes. First, the study summaries included in the survey highlight topics covered in the literature; thus, the survey is a useful resource to researchers wanting to determine previous photovoltaic technology research efforts. Second, the study summaries list major assumptions and conclusions; thus, the summaries can be used to identify key assumptions which could lead to disagreement or concensus between studies. The Sandia National Laboratories Photovoltaic Systems Division is compiling a series of residential photovoltaic topical reports to facilitate technology transfer of the results of National Photovoltaic Program research to industry.[2] To date, however, there has been no comprehensive analysis to compare and evaluate information presented throughout these documents in a consistent and standardized manner. This report provides such an analysis.

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1 S. Sillman et al., Photovoltaic Systems for Residential Applications: A Survey of Recent Literature, SERI/TR-254-1903, October 1983. The topics covered in the survey include design and testing of residential systems, system economics, effects of residential photovoltaic systems on utilities and utility rates, system safety and reliability issues, institutional and market development issues and residential building design for photovoltaic systems.

2 Sandia National Laboratories, Photovoltaic Systems Division, Residential Photovoltaic Systems, draft. The collection of 13 topical reports will include an executive summary, design reports (feasibility assessment, institutional issues, system and array design, the power conditioning subsystem, system installation, operation and maintenance) and background information reports (the utility and photovoltaics, listing of design tools, economic evaluation methods, photovoltaics fundamentals, energy storage and DC loads and combined photovoltaic/thermal flat panel collectors).

The review is designed to provide summary documentation of six major economic studies addressing grid-connected residential photovoltaics in the U.S. Specific objectives of the report are:

- To summarize the key findings of each study.
- To identify the major differences among the studies.
- To identify key economic issues affecting grid-connected residential photovoltaics.

Particular attention is given to the key economic and financial variables: system cost, purchase criteria, tax benefits, economic benefits, and financing options. Key assumptions are reviewed for their applicability and relevance at the residential level. The sensitivity of study results to changes in these economic assumptions is central to the analysis. It would be useful to know, for example, whether or not each of the studies would reach similar conclusions, given similar assumptions. This report provides insights into this question by reviewing the modeling methods of the six studies. Different modeling methods may cause similar inputs to reach dissimilar conclusions. The reviewed studies have been compared in a consistent manner to develop a set of aggregated conclusions.

The review concentrates on six studies that analyze the cost-effectiveness of grid-connected residential photovoltaic systems (Exhibit 1). These six studies were selected based on two criteria. First, the reports share common emphases on developing residential photovoltaic systems with certain engineering design goals in mind, and on performing economic analyses to assess the long-term economic potential of the system design. The economic analyses presented in these studies are performed from the consumer's perspective. The value of grid-connected residential photovoltaic systems to utilities and the level of utility buy-back rates are treated as input assumptions for the economic analyses. Studies with other emphases, including studies that simply derived cost estimates for engineering designs and studies that only assessed the value of

Exhibit 1

Major Studies of Grid-Connected Residential Photovoltaic Systems
Cost-Effectiveness*

U.S. Department of Energy

1. Borden, C.S., Jet Propulsion Laboratory, The Value of Residential Photovoltaic Systems: A Comprehensive Assessment, DOE/ET 20356-8, 1983 (market**).

2. Science Applications, Inc., San Diego County: A Case Study of Opportunities for Grid-Connected Photovoltaic Power Systems, DOE/CS/30047-TI, 1981 (market).

EPRI

3. JBF Scientific Corporation, Assessment of Distributed Photovoltaic Electric Power Systems, EPRI AP-2687, 1982 (market).

4. Science Applications, Inc. Assessment of Distributed Solar Power Systems: Issues and Impacts, EPRI AP-2636, 1982 (market).

MIT Energy Laboratory

5. Tabors, Richard D., Economic and Market Analysis of the PV Technology: Final Report Draft, MIT Energy Laboratory, 1982 (market).

Sandia National Laboratories

6. Buerger, E.J. et al., General Electric Space Division, Regional Conceptual Design and Analysis for Residential Photovoltaic Systems, SAND 78-7039, Vol. I and II, 1979 (engineering).

* Listed by sponsoring agency.
** Study analytical approaches are classified according to criteria specified in Table 1 of this review (Section IV).

residential photovoltaic systems to utilities, were not included in the review. Second, the selections reflect the different analytical work sponsored by each of the research organizations interested in grid-connected residential photovoltaics (DOE, EPRI, JPL, MIT and Sandia).

The review is organized into two sections. The sections are designed to familiarize the reader with study objectives and findings; to develop the economic arguments presented in the studies; and to draw conclusions across studies which will provide insights regarding the long-term economic potential for residential grid-connected photovoltaic systems. The evaluation is initiated with an overview of study objectives and findings (Section III). This section is followed by an evaluation of the economics of residential photovoltaic systems (Section IV), which includes an economic comparison of the studies, including sensitivities, and draws conclusions regarding the presence or absence of cost-effective markets.

III. Study Overviews

1. Assessment of Distributed Solar Power Systems: Issues and Impacts (EPRI-SAI)

   STUDY OBJECTIVE/FOCUS

   - The study stresses the need to include balance of system costs (interconnection, structure and installation, and marketing and product distribution costs) in determining the economic attractiveness of residential PV systems. The importance of recognizing the stringency of user purchase criteria is emphasized when indicating the market potential for dispersed residential PV systems.

   STUDY CONCLUSION

   - The study finds allowable system prices of about \$0.75-\$2.20/Wp (1980 dollars) and allowable module prices of 0 to \$0.55/Wp by the end of 1989. The allowable module price is based on purchase criteria, structure and installation costs, marketing and distribution costs, tax and financial variables, etc.

2. Economic and Market Analysis of the PV Technology: Final Draft Report (DOE-MIT)

   STUDY OBJECTIVE/FOCUS

   - The study consists of several papers describing MIT work with residential photovoltaic economics. Two study areas are of particular relevance to this review. One part calculates allowable PV system costs based on system life, system efficiency, homeowner discount rates, tax incentives, electricity buy-back rates and related factors. A second part of the study details the development and application of a PV market penetration model.

   STUDY CONCLUSION

   - Based on both new and existing research, photovoltaic systems would be economical at module prices in the \$0.70/Wp range and installed system prices in the \$1.50-\$4.00/Wp range in 1986 (1980 dollars).

3. Regional Conceptual Design and Analysis Studies for Residential Photovoltaic Systems (Sandia-General Electric)

   STUDY OBJECTIVES/FOCUS

   - The study provides technical and cost specifications and user purchase criteria for residential roof-mounted PV systems in several regions of the U.S. The study compares several configurations of residential photovoltaic systems (photovoltaics-only, photovoltaics with batteries, side-by-side with thermal, etc.) for economic attractiveness in the mid-1980's based on life-cycle economic criteria.

   STUDY CONCLUSION

   - The study concludes that if arrays are priced at \$0.70/Wp in 1986 (1980 dollars), then residential systems are economical; and PV-only systems are preferred to hybrids.

4. Assessment of Distributed Photovoltaic Electric Power Systems (EPRI-JBF)

STUDY OBJECTIVE/FOCUS

- The study considers the impacts of distributed PV systems on selected utilities. Three classes of impacts are considered: (1) impacts of residential- and utility-owned PV systems on utility generating costs and operations, (2) impacts on the transmission and distribution system, and (3) valuation of PV systems. The study estimates the value of photovoltaics in 1995 based on the impact of the technology on three U.S. utility systems selected to show a range of impacts.

STUDY CONCLUSION

- The study estimates the value of installed PV systems at approximately $1.27/Wp for systems in the Northeast Utilities service area, corresponding to a module cost of just under $0.50/Wp (1980 dollars). This allowable system cost falls within the study's estimated range of single family residential system costs. For the other utilities examined, the allowable system cost falls below the study's estimated system cost range. A low value was derived for the Los Angeles Department of Water and Power and Alabama Power Company systems, even though they are high insolation areas, because the photovoltaic system is assumed to displace low price coal generation, not high price oil. By contrast, Northeast Utilities currently generates with high price oil, and is projecting added nuclear capacity.

5. The Value of Residential Photovoltaic Systems: A Comprehensive Assessment (DOE-JPL)

STUDY OBJECTIVE/FOCUS

- The price at which a specific 4.34 kWp roof-mounted system becomes economically attractive is calculated based on benefits derived from tax assumptions and revenues from electricity sale to the grid. The analysis includes technical and economic/financial sensitivities and covers systems in several U.S. regions.

STUDY CONCLUSION

- The study derives an allowable installed system cost for several U.S. regions ranging from $1-3/Wp in 1986 (1980 dollars). Regional variation in the allowable cost is caused by ownership, financial and tax assumptions, regional factors affecting system load and utility buy-back rates.

6. San Diego County: A Case Study of Opportunities for Grid-Connected Photovoltaic Power Systems (DOE-SAI)

STUDY OBJECTIVE/FOCUS

- The study assesses the market potential for grid-connected photovoltaic power systems in San Diego in 1986 and 1990. The price at which roof-mounted PV

systems in the 2-4 kWp range become economically attractive is calculated based on the avoided cost to the utility and tax benefits.

STUDY CONCLUSION

- The study finds that small systems (2-4 kWp) are attractive in 1986 at prices of \$0.70/Wp for modules and \$1.60/Wp for systems (1980 dollars) if existing tax credits remain in place.

IV. Grid-Connected Residential Photovoltaic System Economics

The market specifications and economic modeling assumptions employed in each study form the driving force behind conclusions of photovoltaic cost-effectiveness. In this section, these study assumptions -- and the results obtained through their use -- are compared to determine where conclusions differ. First, market specification assumptions are highlighted. Then, economic modeling methods, model parameter values and evaluation results are compared.

Table 1 shows categories useful for defining the residential photovoltaic market analyzed in each study. The table also defines the approach taken in each study to analyze the cost-effectiveness of the technology. Each of the categories selected for the table has an impact on the cost-effectiveness evaluation performed in each study. The following discussion highlights the impacts.

First, the studies are divided into two types -- market approaches and engineering approaches. The market studies emphasize design and costing of photovoltaic systems to meet the requirements of specific market applications. The engineering studies concentrate on more detailed system design and component costing. They are likely to have paid less attention to picking actual test market applications for their designs. Instead, the systems in engineering studies tend to emphasize design of a photovoltaic system that can carry a cost-effective load. This load is then translated into a system size which may or may not be compatible with available home roof space.

Second, the range of potential grid-connected photovoltaic applications defined in the studies is specified. Many of the studies consider a number of regional applications. Such studies were able to highlight the variation in the economics of residential photovoltaics based on variations in residential electric loads, insolation, electricity buy-back rates and other economic parameters affecting cash flows. Some of the studies are site-specific,

Table 1

Comparison of Major Differences Among the Studies

Study	Study Type	Study Scope	Market Year	System Size (kWp)	Analytical Method	Home Type	Economic Evaluation Includes Debt Interest in the Cash Flows
EPRI-SAI	Market	General Ownership Issues	1989	5	Breakeven Price	N/A	Yes/No 3/
DOE-MIT	Market	Regional	1986	6 2/	Breakeven Price	New	Yes
Sandia-GE	Engineering	Regional	1986	9.5 2/	Cash flow with set capital cost	New	Yes
EPRI-JBF	Market	Regional	1995	Optimized	Breakeven Price	New	Yes
DOE-JPL	Market	Regional	1986	4.34	Breakeven Price	New	Yes
DOE-SAI	Market	Site Specific 1/	1986/1990	2-4	Cash flow with set capital cost	New	Yes

1/ San Diego

2/ 0.1 kWp/m^2 at 10 percent efficiency

3/ Debt interest is included in the life-cycle costing sensitivity case; not in the simple payback base case.

constraining use of such studies to make statements about cost-effectiveness and market potential other than for a specific application.

Third, the economic assessment base year has an impact on photovoltaic cost-effectiveness because it determines the values of time-dependent economic parameters, including electricity purchase and buy-back rates. For instance, suppose the cost-effectiveness of two identical residential photovoltaic applications is being assessed. The only difference will be that one of the residences is evaluated in a market starting a few years after the system in the other residence goes on-line. The residential system that started up in the later year may be more cost-effective because of a time-dependent improvement in economics. For instance, real electricity buy-back rates could increase. Four of the six studies are based on the same market year (1986). Two of the studies are based in later years.

System size -- given system insolation and efficiency characteristics -- defines the system electricity output, which drives the photovoltaic system cost-effectiveness evaluation. As previously mentioned, the study type -- market or engineering -- tends to influence system size. In market studies, the size of the photovoltaic system ranges from about 2-6 kWp. Engineering studies use larger system sizes, such as the 9.5 kWp system specified in the Sandia-GE study.

Each of the reviewed studies defined a purchase criterion to be met for the residential photovoltaic system to be considered cost-effective. Three of the studies conducted breakeven cash flow analyses employing discounted cash flows. In these analyses, system size and load were defined. Given such information, cash flows specifying operation, maintenance, electricity sales and tax incentives can be defined. A breakeven capital cost (often called an "allowable" cost in the studies) equals the net present value of all cost and benefit cash flow streams -- the point at which the technology is marginally cost-effective. One of the studies conducted a breakeven capital cost analysis

using a simple 5-year payback method to determine the capital cost. Two of the studies -- those with site-specific or engineering emphases -- specified both system size and system capital cost. Cash flow analyses were then conducted to determine whether or not the benefits of operating a system exceeded the operating costs.

A buyer's willingness to invest in residential photovoltaic systems is reflected in the purchase criteria employed when making the investment. Two purchase criteria were used in the studies:

- Life-cycle costing with the photovoltaic system cost financed by a new home mortgage
- Simple payback

Consumers using a life-cycle costing criterion over the full life of the technology are much more willing to invest than are consumers using the simple payback criterion with a short-term required payback.

In the studies using life-cycle costing decision criteria, the photovoltaic investment was financed by a new home mortgage; and the debt interest cash flow was included in each analysis. Use of this criterion is based on certain assumptions about buyer investment behavior:

- The buyer may resist making large initial cash outlays for the energy system even when it will generate a net savings in future fuel expenses that will eventually more than cover the initial investment, over the investment lifetime.
- The buyer will be unlikely to occupy the home for the total life of the investment; therefore, the buyer will only benefit from a portion of the total fuel savings accrued over the system lifetime.

The reviewer suggests that a new home owner can overcome these problems by including the photovoltaic investment in the mortgage. The initial cash outlay is reduced. Since the buyer is likely to sell the home before paying off the full investment, the actual benefits realized will be the net annual savings (including debt interest expense) accrued while the buyer owns the home compared

to only a portion of the full first cost of the photovoltaic investment. This comparison may produce a reasonable return.

The studies use a simple payback decision criterion to reflect much greater buyer resistance to making the photovoltaic investment. To calculate simple payback, the buyer determines net first year savings. These first year savings are divided into the total installed capital cash outlay to be made. The result is the number of years before the initial cash outlay is recovered, without recognizing the time value of money or the changes in net benefit cash flows that are recognized with a life-cycle costing criteria (and which can help make investments evaluated with life-cycle costing methods look more attractive).

Table 2 shows the critical model parameters used in analyzing the cost-effectiveness of the photovoltaic market described in Table 1. Additionally, it shows the photovoltaic system costs that are either derived as breakeven costs or set as specific capital costs.

The following discussions present an overview of the studies, looking at similarities and variations among the study analyses of the economics of residential photovoltaics. The overview yields several concluding statements which can be made about photovoltaic system economics, including statements about the conditions under which such systems become cost-effective. Statements made in this section cover the two key parts of an economic analysis -- (1) cost specification, and (2) purchase criteria. They tend to reflect the sensitivity tests conducted in the studies to show the range of economic conditions under which residential photovoltaic systems would be cost-effective.

Table 2

Comparison of Selected Economic Assumptions

Study and Year Performed	System Size (kWp)	Purchase Criteria	Electricity Buy-Back Rate (1980 cents/kWh)	Tax Credit 1/ (percent)	Debt Fraction (percent)	Module Cost (1980$/kWp)	Balance of System Cost 4/ (1980$/kWp)	System Cost (1980$/kWp)
EPRI-SAI (1982)	5	5 Year payback	6.8	0	0	N/A	860+ 90% of module FOB cost	750
DOE-MIT (1982)	6	20 year life-cycle	6.3	0	90	N/A	N/A	1500
Sandia-GE (1978)	9.5	20 year life-cycle	1.5-3 2/	0	80 3/	700	285+ $1420 Fixed Charge 5/	1135
EPRI-JBF (1982)	2	20 year life-cycle	3-6	0	80	300	750	1050
DOE-JPL (1983)	4.34	30 year life-cycle	1.5-7.5	0	80	0-2000	about 1250	1000-3000
DOE-SAI (1981)	2-4	30 year life-cycle	6.6	55	60	500	500+ 35% of Module FOB Cost	1300

1/ Combined State and Federal, Base Case.
2/ Electricity rates increase at 2-6 percent real per year.
3/ Not specified in study. Assumed to correspond with fraction used in other studies.
4/ Marketing, Distribution, Structure, Installation.
5/ Including balance of system costs and array mark-up.

Similarities Among the Studies:

- Given financing incentives and tax incentives, residential photovoltaic systems are attractive in many areas of the U.S. at prices of \$0.70-\$1.40/Wp for modules and \$1.60-\$3.20/Wp for installed systems (1980 dollars).

- Exclusion of financing incentives and tax incentives from the analyses has a significant adverse impact on system cost-effectiveness.

  - Given financing incentives and tax incentives, photovoltaic system cost-effectiveness is achieved at about \$2.60/Wp (1980 dollars) in the EPRI-SAI study life-cycle costing case.

  - Without financing incentives and tax incentives, system cost-effectiveness is achieved in the EPRI-SAI study 5-year payback case at a much lower system cost level, \$0.75/Wp (1980 dollars).

  - Given financing incentives and tax incentives, systems cost-effectiveness is achieved at over \$3/Wp (1980 dollars) in the MIT study.

  - Without financing incentives and tax incentives, sensitivity tests on the MIT base case yield a lower cost-effectiveness point -- less than \$1/Wp for installed systems.

  - Given system cost-effectiveness in the \$1/Wp range (no financing incentive; no tax incentive cases), module costs must be near zero if balance of system costs are at the levels estimated in the studies. Balance of system costs in all the studies are above \$0.75-\$1/Wp, with most projections in the \$1-2/Wp range.

  - From the preceding statements, the reviewer concludes that the photovoltaic system might be cost-effective at about \$3/Wp given financing and tax incentives. Without financing and tax incentives, the cost-effective system price is substantially reduced to about \$1/Wp.

  - Additionally, the reviewer suggests that the technical feasibility of the \$1/Wp system that is cost-effective without financing and tax incentives would have to be assessed.

- Within a reasonable range, tax incentives, level of utility buy-back rates, escalation of utility buy-back rates, and amount of electricity sold to the grid have the most impact on system cost-effectiveness, based on analysis of study economic sensitivity tests.

  - Tax incentives: Typically, the presence of the 40 percent federal tax credit is the most important cost-effectiveness determinant. For system costs under \$10,000, the tax credit roughly doubles the break-even system cost. As system costs rise above \$10,000, the impact of the tax credit decreases proportionately. (A 4 kWp system, typical for residential systems, would cost about \$10,000 in 1986 based on module prices of \$0.70/Wp -- \$1.60/Wp for installed systems in 1980 dollars, escalated to 1986 dollars at an 8 percent inflation rate.)

- Level of utility buy-back rates, Escalation of utility buy-back rates, and Amount of electricity sold to the grid: At real escalation rates of at least 2-3 percent for electricity buy-back rates, the electricity buy-back rate has a strong impact on system cost-effectiveness when evaluated over a 20- to 30-year project life.

- The cost-effectiveness of photovoltaic systems with storage depends upon the level of investment made to add storage capacity, the net expense saved by keeping the PV electricity on-site and the revenue that could be generated by selling electricity to the grid. Low battery costs, low utility buy-back rates and high electricity purchase rates improve the cost-effectiveness of storage systems. As battery costs and utility buy-back rates increase, storage becomes less cost-effective.

Variations Among the Studies:

- Residential Purchase Criteria

  - Most studies perform a discounted cash flow analysis at a 10 percent discount rate over a 20- to 30-year system life.

  - More stringent purchase criteria are explored in the EPRI-SAI study. The use of a 5-year payback criterion requires an installed system to cost less than $1/Wp for cost-effectiveness to be achieved.

  - The 20-year life-cycle costing sensitivity case presented in the EPRI-SAI study gives results comparable to other studies using life-cycle costing criteria.

  - Studies using purchase criteria comparable to the stringent EPRI-SAI 5-year payback criterion reach conclusions comparable to the EPRI-SAI study conclusions.

- Cost Specifications

  - The level of balance of system costs varies among the studies, ranging from $0.75/Wp to over $2.00/Wp.

  - When balance of system costs are at the upper end of the range ($2.00/Wp), systems are not cost-effective, even if evaluated over a 20-30 year life at a 10 percent discount rate. Moreover, as module prices rise above $0.70/Wp, the commensurately increasing downstream costs rapidly reduce photovoltaic system cost-effectiveness.

APPENDIX
REPORT SYNOPSES

Assessment of Distributed Solar Power Systems: Issues and Impacts
Science Applications, Inc.

EPRI AP-2636, November 1982

STUDY OBJECTIVE AND FOCUS

The study stresses the need to include interconnection, structure and installation, and marketing and product distribution costs in determining the economic attractiveness of residential PV systems. The importance of recognizing the stringency of user purchase criteria is emphasized when assessing the market potential for dispersed residential PV systems.

METHODOLOGY

This study emphasizes the consideration of purchase criteria used by owners selecting PV systems. Additionally, the study analyzes the costs of connecting a residential PV system to the grid, and the problems faced by the utility to provide inter-connection services.

The value, or allowable price, of the distributed solar power system is defined using owner purchase criteria to evaluate user benefits. The allowable price defined in this study is the factory price of the power generation equipment. Interconnection, structure and installation, and marketing and product distribution costs are added as mark-ups.

FINDINGS AND CONCLUSIONS

A number of distributed solar power system applications were evaluated, resulting in the following findings:

- It is important to evaluate system economics using realistic purchase criteria. Criteria actually used are likely to include short payback periods, high discount rates, or high rates of return. This results in allowable system prices that are typically less than half those derived in long-run life-cycle cost analyses using lower discount rates.

- Marketing and distribution costs can make the allowable generation equipment price a factor of two smaller than the allowable total installed system price.

- Other important parameters in determining system attractiveness are capacity factor, displaced electricity value, tax credits, and purchase criteria.

- Interconnect costs (per kW) increase dramatically as system size decreases. For small (less than 5 kW) systems, the interconnect costs can approach the allowable system price, leaving little for the generation equipment costs.

- Safety hazards, especially for distributed solar systems in remote locations, are the greatest current technical interconnect concern.

- The technical requirements and costs of distributed system interconnections will likely increase with increasing local market penetration.

- For some unresolved technical issues, the costs of alternative solutions are well known. The need for transformers and the quality of protective relays dominate the interconnect cost for residential systems.

- Further evaluation is required on the technical issues of harmonics, power factor correction, and the adequacy of protective switch gear supplied by distributed system manufacturers.

- Investor ownership of PV systems is financially attractive. Resolution of technical and institutional issues is easier for these systems than for systems under other ownership forms.

Economic and Market Analysis of the PV Technology
Final Report Draft

Richard D. Tabors

MIT Energy Laboratory, August 1982

STUDY OBJECTIVE AND FOCUS

The study consists of several parts. One part calculates allowable PV system costs based on system life, system efficiency, homeowner discount rates, tax incentives, electricity buy-back rates and related factors. A second part of the study details the development and application of a PV market penetration model.

METHODOLOGY

The allowable cost of a PV system (costs at which the net present value of project cash flows is zero) is calculated using a mortgage finance cash flow model. Several sensitivity analyses were performed to assess the impact of PV cell efficiency, insolation, discount rate, tax credits, mortgage downpayments, mortgage rates, utility rates, inflation rates and tax rates on the allowable cost. The pre-tax cash flow streams included in the analysis are capital cost; electricity sales; operating, maintenance and insurance expenses; and mortgage payments. Interest and tax streams are then added.

A market pentration model, PV1, was developed to model residential consumer acceptance of PV technology. The model calculates PV system market potential based on a cash flow analysis. The model then introduces government purchase incentives and calculates market acceptability of the PV system based on probability of purchase and on buyer awareness of the product, confidence in the product, etc.

FINDINGS AND CONCLUSIONS

- Photovoltaic system costs are the major barrier to market acceptance. When photovoltaic system costs are high and far from competitive, government subsidies are unlikely to accelerate market acceptance. When photovoltaic system costs approach competitive levels, subsidies are very effective.

- Market development spending is essential and must be done early. Without market development spending, the public remains unaware of PV systems; and the technology is perceived as too risky to buy.

- Allowable installed system costs range from \$1.50/Wp to \$4.00/Wp (1980\$), depending on certain variables. The most important variables are insolation, tax benefits, array efficiency, utility buy-back rates, rate escalation, and discount rates.

- Other lesser discussed considerations include battery storage (no benefit), taxation of electricity sales (negative impact), thermo-photovoltaic systems (no benefit), and new construction (positive impact).

- Electricity buy-back rates at more than 80 percent of selling rates will have a major impact on the configuration and optimal sizing of systems in dispersed PV applications and on electricity storage requirements.

Regional Conceptual Design and Analysis Studies for Residential Photovoltaic Systems

E. J. Buerger et al.
General Electric Space Division
Vols. I and II, SAND 78-7039, January 1979

STUDY OBJECTIVE AND FOCUS

The study provides technical and cost specifications and uses life-cycle costing purchase criteria to define economic attractiveness for residential roof-mounted PV systems in several regions of the U.S.

METHODOLOGY

This study approaches costing of the residential PV system from an engineering design perspective. In this respect, it differs from most of the other studies reviewed, which calculate the allowable PV system costs needed for a cost-effective market to develop. The study assesses the technical and economic performance of residential photovoltaic systems and recommends the most promising systems for future testing. Costs for the PV systems analyzed include array costs, inverter and other grid-connection or battery storage costs, and cost mark-ups for distribution and installation of the PV system.

The economic value of residential photovoltaic systems is assessed by comparing levelized annual energy costs, including mortgage, tax, insurance, and operating and maintenance expenses. The study includes financing cash flows in its assessment of PV system cost-effectiveness.

FINDINGS AND CONCLUSIONS

- For most sites considered, residential PV systems are economical at $0.50 per peak watt array costs (1975 dollars).
- A residential test program is recommended to assure that technology development is pursued to attain viable 1986 cost levels.
- Residential PV-only solar systems show a potential economic viability as good as or better than other solar energy options in all regions evaluated.

- Economic evaluations show residential PV systems without batteries are preferred over systems with batteries. Systems without batteries require a utility electricity sell-back rate at 40-50 percent of the electricity buy rate.

- Fixed-panel, roof-mounted, passively-cooled PV solar arrays characterize the most suitable residential systems.

Assessment of Distributed Photovoltaic Electric Power Systems
JBF Scientific Corporation

EPRI AP-2687, October 1982

STUDY OBJECTIVE AND FOCUS

The study considers the impacts of distributed PV systems on selected utilities. Three classes of impacts were considered: (1) Impacts of residential- and utility-owned PV systems on utility generating costs and operations, (2) Impacts on the transmission and distribution system, and (3) Valuation of PV systems. Three utilities were selected to show a range of impacts of residential photovoltaic systems. These utilities were the Los Angeles Department of Water and Power, Alabama Power Company and Northeast Utilities Service Company, chosen to represent regions with high, intermediate and moderate insolation potential, respectively.

METHODOLOGY

The economic potential for residential ownership of distributed PV systems is evaluated by calculating an economic breakeven value. This value is the maximum that could be paid for an installed PV system so that the net present value of the investment cash flow streams would be zero. In designing and sizing distributed photovoltaic systems for the study, design parameters considered included load characteristics, electricity storage capability, energy management requirements, utility interface requirements and system physical constraints.

Additionally, the assessment of PV system worth includes the potential economic impacts of distributed photovoltaic systems on utility generation mix and on subtransmission and distribution networks.

FINDINGS AND CONCLUSIONS

Potential Value:

- The potential value of distributed PV systems is derived primarily from fuel savings.
- The potential value of distributed PV systems is influenced much more strongly by the cost of fuels that may be saved than by variations of insolation among the utility service areas.
- In general, utility-owned systems for residential applications have breakeven values that are significantly less than those of customer-owned systems.
- The value of distributed PV systems without storage is higher than for those with storage, if excess energy is returned to the grid for a credit of at least 75 percent of the average cost of fuels saved by the utility.
- The potential value of PV systems owned by a utility and distributed within its transmission and distribution network is comparable to that of central station configurations--but the distributed systems may have cost penalties associated with added safety and control equipment requirements.
- Variations in public policy alternatives, such as direct tax credits and low-interest loans, could significantly affect the potential value of distributed PV systems.
- The discounted payback period and real fuel cost escalation rate have the greatest influence on PV system value.

Projected System Cost Estimates:

- Cost of the PV arrays (as delivered, without interconnecting wiring or supporting structure) appeared to influence estimated system cost the most.
- Power conditioner, array support structure and electrical installation costs influence estimated system costs about equally.
- Estimated costs for customer-owned distributed PV systems are quite sensitive to assumptions about PV system marketing and distributing costs.

Potential Utility Impacts:

- Market penetration of residential PV systems will be promoted given substantial reductions in installed capital costs and favorable economics. By 1995, penetration could occur in regions using expensive fuels for a large portion of electricity generating capacity.

- The potential for distributed PV units significantly affecting utility industry load by 1995 is small.

- PV system cost reductions may be impeded by relatively modest penetrations of residential-and utility-owned systems markets since the industry production capability is limited enough to cause upward price pressure as market demand starts to pick up.

The Value of Residential Photovoltaic Systems:
A Comprehensive Assessment

C. S. Borden

Jet Propulsion Laboratory, September 1983

STUDY OBJECTIVE AND FOCUS

The price at which a specific 4.34 kWp roof-mounted PV system becomes economically attractive is calculated based on benefits derived from tax assumptions and revenues from electricity sale to the grid.

METHODOLOGY

An economic analysis was conducted to assess the cost-effectiveness of a specific roof-mounted residential PV system. The assessment was performed using a breakeven calculation to define the PV investment level at which the net present value of the investment cash flows is zero. In performing the assessment, regional differences in PV system economics were considered.

FINDINGS AND CONCLUSIONS

- Residential roof-mounted utility-interactive photovoltaic systems appear to have potentially attractive large-scale application.
  - A series of technology breakeven costs is calculated. The breakeven cost is the investment at which net present value of all investment cash flows equals zero. The costs range from $1 to $3 per peak watt (1980 dollars) for a 4.34 kWp ac system.
  - Owner financial and tax considerations cause large variations in breakeven costs.
  - Primary factors in variation of breakeven costs are local weather conditions, existing electric utility generation capacity and fuel mix, customer load profiles (which affect purchase and buy-back rates), and variation in state taxes.
  - Locations with the highest insolation values are not necessarily the most economically attractive sites.
  - Residential PV systems connected in parallel to the utility demonstrate capability for high percentages of electricity sell-back to the grid.

- PV technology cost reduction and resolution of potential institutional impediments are required for a residential PV market to become a major grid-connected electricity source.

San Diego County: A Case Study of Opportunities for
Grid-Connected Photovoltaic Power Systems
Science Applications, Inc.

DOE/CS/30047-T1, April 1981

STUDY OBJECTIVE AND FOCUS

The study assesses the market potential for grid-connected photovoltaic power systems in San Diego. The price at which roof-mounted PV systems in the 2-4 kWp range becomes economically attractive is calculated based on the avoided cost to the utility and tax benefits.

METHODOLOGY

An economic analysis is performed to assess the market potential for site-specific grid-connected photovoltaic power systems in San Diego. Criteria for installing photovoltaic systems are that the costs of installing and operating the system must be out-weighed by the benefits derived from the operation. Benefits are defined as the cost of conventional electricity displaced (the "avoided cost" for the utility). Early, sustained PV markets, as opposed to one-time markets or mature markets, are considered.

The study looks at the economics of grid-connected PV systems under various ownership forms. These forms include utility ownership, residential ownership and third party ventures.

FINDINGS AND CONCLUSIONS

- At system costs of $1.60/Wp installed (1980 dollars), residential photovoltaic systems would be attractive to San Diego homebuyers in 1986.
- At installed system prices above $1.60/Wp residential systems quickly become unattractive.
- Tax credits are indispensable to the early development of a residential photovoltaic systems market.
- Higher fuel prices have little effect on residential photovoltaic systems value.
- Residential photovoltaic systems in San Diego will not receive a capacity credit.